AIR TRAFFIC CONTROL SPECIALIST PERFORMANCE MEASUREMENT DATABASE

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16. Abstract

The Air Traffic Control Specialist (ATCS) Performance Measurement Database is a compilation of performance measures and measurement techniques that researchers have used. It may be applicable to other human factor research related to air traffic control (ATC). This database is a tool that can be used in conjunction with ATC simulators, generic sector configurations and scenarios, and other procedures used in assessing ATC system safety and effectiveness. Having a set of measures with standardized parameters will increase the reliability of results across experiments and enable comparisons of results across evaluations. At this time, it is unlikely that the database includes all of the measures that are applicable to ATC assessments. However, the database is designed to be an adaptive research tool, and the authors invite your nominations of other measures for the database.

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Executive Summary

The Air Traffic Control Specialist (ATCS) Performance Measurement Database is a compilation of performance measures and measurement techniques that researchers have used. It may be applicable to other human factor research related to air traffic control (ATC). The database provides a valuable tool to assist evaluations of air traffic equipment. Using standard database techniques, a researcher can select measures appropriate to the experimental questions under study. The database provides citations for the primary sources from which the measure was obtained and additional references for further information. Further, the authors have included a bibliography of human performance measurement references as an additional source of reference information.

The database represents an important tool that can be used in conjunction with ATC simulators, generic sector configurations, scenarios, and other procedures used in assessing ATC system safety and capacity. Having a set of measures with standardized parameters will increase the reliability of results across experiments and enable comparisons of results across evaluations.

1. Introduction

The Federal Aviation Administration (FAA) has established strategic goals of improved Air Traffic Control (ATC) system safety and capacity. Measures of ATC system performance and Air Traffic Control Specialist (ATCS) performance are required to accurately determine which elements of the system need to be changed to achieve those goals and to determine when progress has been attained. The primary goal is to develop a comprehensive set of ATCS performance measures that relate to ATC system safety and capacity. Development of this database is one of several objectives required to achieve this goal.

1.1 Background

There are several well-known measures of overall ATC system effectiveness used in assessments (Hopkin, 1995). However, the task of controllers within ATC systems primarily involves cognitive activities, which are difficult to measure directly. Instead, researchers must infer evaluations of many aspects of ATCS performance. Although a large number of performance measures have been used in ATC evaluations, their relationships to system effectiveness are inconsistent and not well understood. Whereas many of the elements affecting overall system performance are well documented, the relationships between controller performance and system effectiveness are still in initial stages of exploration

ATCS performance measures allow researchers to examine the relationship between what the controller does and how well the system works. Performance measures are useful for a wide range of activities, including

- mitigation of risk;
- validation of operations concepts, operational requirements, and equipment specifications;
- evaluation of ATCS/computer functional allocation;
- assessment of the effectiveness of proposed procedures and ATCS/system interactions;
- development of display design;
- identification of design incompatibilities;
- evaluation of information displays and ATCS interface usability;
- diagnosis of usability and effectiveness issues to identify limiting factors;
- determining benefits for cost-benefits analyses;
- identifying sources of human error and methods to reduce them; and
- selection and training of personnel.

A primary goal of human factors research in ATC is to establish the link between ATCS performance and system performance. One of the objectives of the ongoing research activities at the FAA William J. Hughes Technical Center has been to identify this relationship. The National Airspace System (NAS) Effectiveness Model (Figure 1) conceptualizes the relationships between variables of NAS safety, efficiency, capacity, and controller performance.

This model illustrates how the ability of controllers to adapt to changes in the dynamic ATC environment impacts system effectiveness. For example, fluctuations in separation distances influence system capacity and affect the taskloads of controllers. ATCSs must have the ability to allocate resources to adjust for changing system demands without compromising safety or effectiveness. The impact of system effectiveness on aviation operations is significant in terms of safety, flight delays, and excess fuel usage. Factors such as the characteristics of the air traffic, weather, and the air carrier operating procedures affect ATC system effectiveness. However, human performance such as the behavior of ATCSs, airway facilities specialists, and supervisors plays a major role in defining system effectiveness.

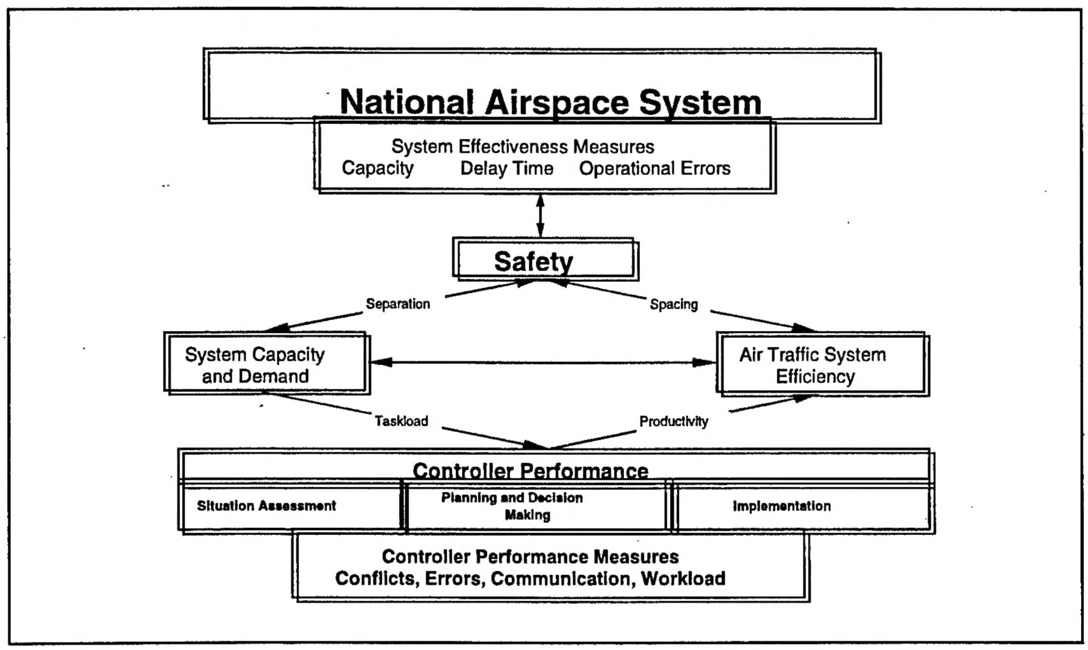

Figure 1. National Airspace System Effectiveness Model.

To study ATCS performance, it is necessary to understand their critical functions, tasks, and associated behaviors. Because ATC is, in large part, a cognitive activity, ATCS performance measures should be relevant to the performance of cognitive tasks. PERI Technologies and its contractors developed the ATCS Functional Performance Model, shown in Figure 2, through review of various ATC task analyses of operations, concepts, current theories, and controller input. The model identifies the relationships between the controller's primary activities and associated behaviors. These relationships identify appropriate measures that assess the quality and effectiveness of those activities and behaviors.

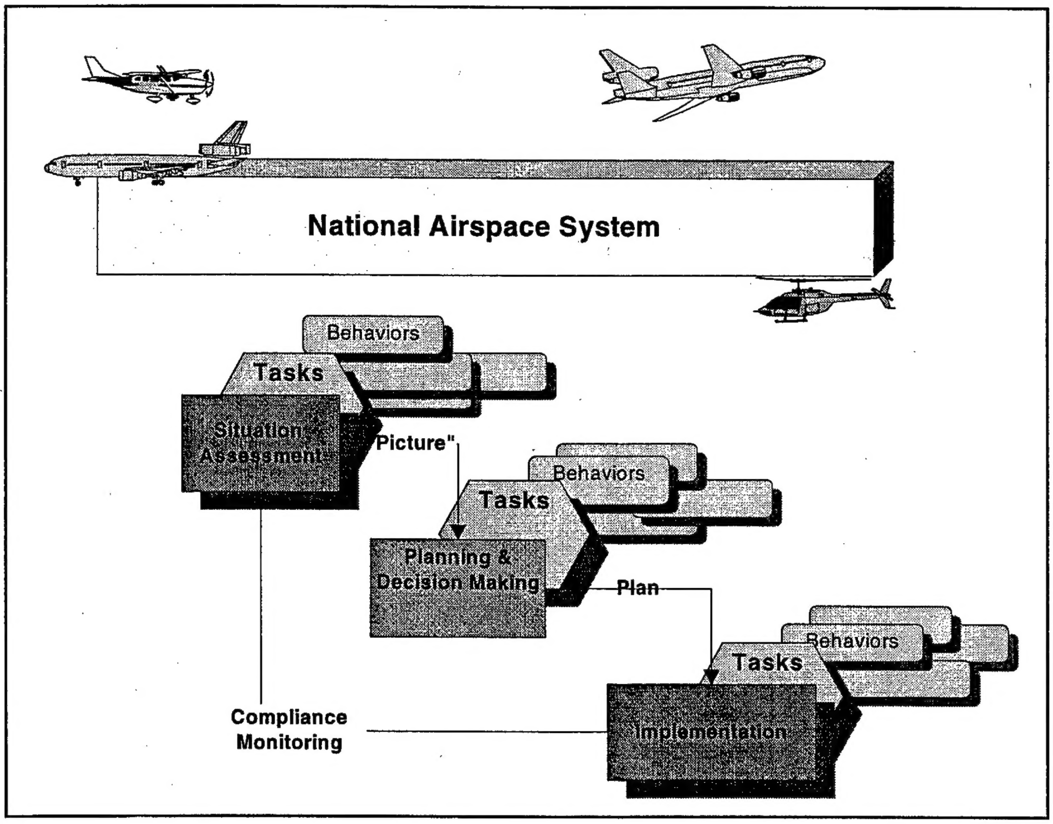

Figure 2. ATCS Functional Performance Model.

To analyze the wide range of ATCS activities, the model divides the overall task into groups of related activities that have a start point, an identifiable process, and an endpoint or result. This model classifies ATCS functions into three categories (Situation Assessment, Planning and Decision Making, and Implementation) and describes the behaviors occurring in a sequential fashion. To make an effective decision, the ATCS must have developed a high level of situation awareness. These variables influence system effectiveness, and nearly all of the controller tasks can be classified under one or more of these major categories. Each functional category is characterized by its associated tasks, and each task involves observable behaviors. This model is useful for categorizing the many accepted and potential performance measures that currently exist in the literature.

Many tools are needed to enable ATC researchers to effectively apply this model and evaluate these performance measures in the context of their research. The performance measurement database is one such tool.

1.2 Purpose

There are two important purposes for developing and applying a performance measurement database. The first is to compile effective ATCS performance measurement techniques into a single source. The second is to promote standardization of parameters across research projects and, therefore, enable comparisons of results across evaluations.

This database will be particularly valuable for researchers with limited exposure to ATC research methods. The authors assembled this database in Microsoft Excel rather than in a more complex database manager because of its near universal availability. Further, such software allows researchers to explore for measures appropriate to the experimental questions they are addressing.

1.3 Value to ATC

The primary objective of performance measurement is to provide a better understanding of NAS critical elements and to help to diagnose and solve system performance issues. From a human factors research standpoint, one important question is how to establish the link between ATCS performance and system effectiveness.

The ATCS performance measurement database is a compilation of measures and measurement techniques that have been proven effective for use in human factor research related to ATC. Figure 3 illustrates some of the potential applications for this database. The following paragraphs describe the elements in Figure 3.

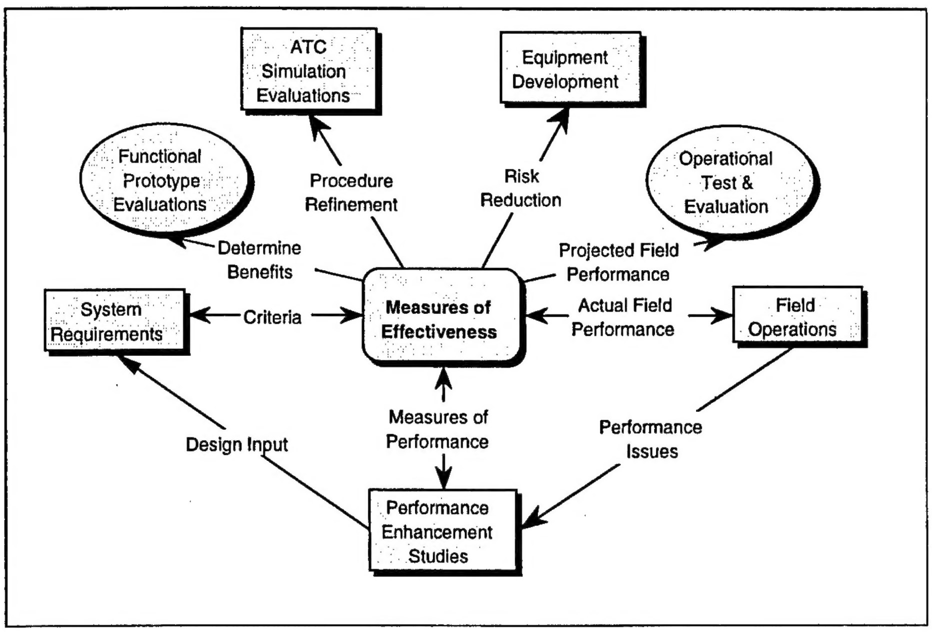

Figure 3. Database applications.

Functional Prototypes. Measures of performance and effectiveness are essential for cost-effective system development. Functional prototypes can provide data to determine the potential benefits of proposed NAS functions. The cost of prototype evaluation is minor compared to the cost of equipment development and design changes late in the process. Evaluation of functional performance can restrain the tendency to design sophisticated, complicated software with a heavy investment and little demonstrated benefits.

ATC Simulation Evaluations. ATC simulation evaluations are used to examine the relationship between proposed changes in equipment, operating procedures, and ATCS performance. These comparisons can then be used to identify potential problem areas before major investments are made in development and implementation. The results of simulations provide a basis for changes that ensure compatibility with the workforce and user acceptance. Changes made early are much less costly and less disruptive to the development schedule.

Equipment Development. The equipment development process progresses through the stages of initial design concept, through detailed design, to production. Performance measurement is the only objective measure of progress during demonstrations and provides a basis for determining if the equipment will achieve the performance goals. Performance measures that maintain a focus on end-item performance relative to the system goals help to ensure that the final product meets expectations.

Operational Test & Evaluation (OT&E). Performance measures can provide data to support or refute the subjective evaluations of subject matter experts. Performance measurement imposes a method that ensures reliability of the results. Generic sectors and standard traffic scenarios can be used to avoid the difficulty of comparing data from ATCSs with different experience. Standardized procedures will help comparison of results from different evaluations. OT&E often does not adequately address human performance issues. The presence of a readily available measurement set may improve the situation in the future.

Field Operations. Currently, we measure ATCS effectiveness in terms of arrivals and departures and the amount of delay associated with those operations. These numbers are compared to the engineered performance standards for a particular airport under a given weather condition and runway configuration. Operational errors are calculated in numbers per facility and are used as an indicator of safety measurements. Certain individual ATCSs and teams of controllers are more effective by reaching higher numbers of operations while committing fewer operational errors than others. Field evaluations of system and individual performance are limited under Labor Management Relation (LMR) Agreements and are subjectively completed by supervisory personnel as being either satisfactory or not satisfactory. Basic tools for performance improvement and systems enhancement are restrained by an extremely high percentage of satisfactory measurements in the system and the LMR Agreements on over-the-shoulder and tape-talk evaluations. Through performance issue studies, the Research Development and Human Factors Laboratory located at the Technical Center can provide necessary data to substantiate the needed support for change.

2. Database

The database contains performance measures that researchers have used for assessing ATCS performance. The database and associated references are included as Appendix A and can also be accessed and downloaded via the FAA William J Hughes Technical webpage (www.faa.tc.gov). An additional source of human performance measures are contained in Appendix B. At this time, it is unlikely that the database includes all of the measures and measurement techniques that are applicable to ATC assessments. However, it is intended to be an adaptive research tool, and the

authors invite your nominations of other measures for the database. One of the most important features of this database is that any new, valid measures of performance and measurement techniques can be easily integrated and the database automatically updated.

2.1 Database Description

The layout of the database and the process for extracting information from it appear in Figure 4. Filtering the database can be done by searching keywords, a specific reference, or measurement type. Probably the most efficient method of searching is by measurement type. As shown in Figure 4, the definitions for each measurement type are located within the database and can be easily accessed. For example, if a researcher is interested in what performance measures are associated with examining situation assessment in the en route environment, he or she can filter the database specifically for those items. The database then produces a listing of references of previous studies, the performance measures, and the measurement techniques associated with situation assessment and the en route environment. The researcher can then decide on which performance measure or measurement technique best suits requirements of the current research question

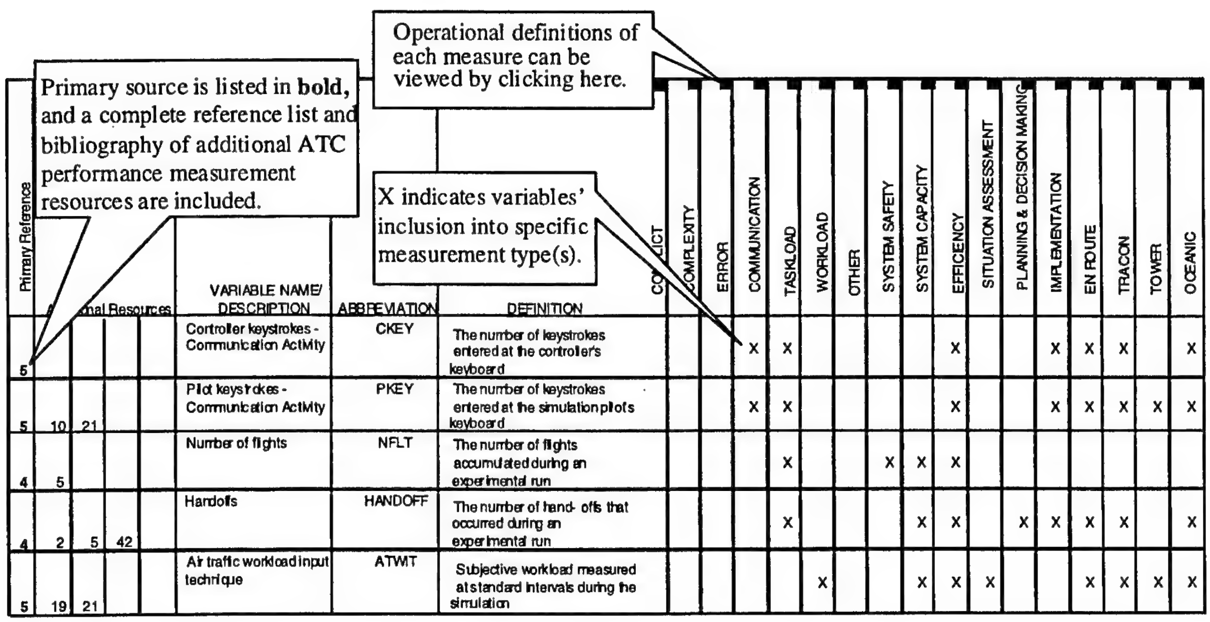

Figure 4. Database construction and features.

2.2 Database Configuration

The database is structured around four categories in which ATCS and ATC measures can be obtained: ATCS Performance Measures, Measures of Air Traffic Effectiveness, the ATCS Functional Performance Model, and the applicable Air Traffic Environment. The types of measures included within each category are defined in the following sections.

2.2.1 ATCS Performance Measures

Performance measures included in this category describe how effective the controller, control team, or system is in accomplishing ATC activities. Some major measures are delays to traffic and violations of separation rules.

Conflict: Violation of safe separation minima between two aircraft. In terminal airspace, a conflict occurs when the distance between two aircraft is <3 miles laterally and <1000 ft vertically. En route conflicts occur when spacing becomes <5 miles laterally and <1000 ft vertically. At altitude above Flight Level 290, the minimum vertical separation distance is 2000 ft (FAA, 1998). There are exceptions, such as when one pilot sees the aircraft ahead and accepts visual separation, or both aircraft are established on parallel localizers.

Complexity: Sector and traffic characteristics that cumulatively add to create a complex set of rules, requirements, and tasks for the controller when controlling aircraft in the sector. ATC complexity is composed of sector and traffic complexity factors such as control adjustments (i.e., merging, spacing, and speed changes; climbing and descending flight paths; and mix of aircraft types). However, the authors recognize that a considerable amount of confusion exists about this construct and, like human workload, there is unlikely to ever be universal agreement concerning its meaning.

Error (Conflict and Non-conflict): A conflict error (operational error) occurs when a failure of equipment, human, procedural, and/or system elements, individually or in combination results in less than the separation minima. Non-conflict errors include, but are not limited to, misidentification of information from the radar display, acceptance of incomplete position information, and interpreting flight progress strips incorrectly.

Communication: Typical ATCS-to-aircraft communications involve using a standard phraseology with aircraft identification, destinations, departure instructions, altitude assignments, holding instructions, and flight plan modifications. Communication between controllers includes coordination between and within sectors, handoffs, and pointouts.

Taskload: System demands placed upon the controller by the current situation, including air traffic volume, mix, complexity of routings, and weather; the number of tasks or frequency of task occurrence associated with a specific job.

Workload: The effects of taskload on the individual controller and the degree to which he/she accepts it. Workload is influenced by the controller's internalized standards of performance, ability, and experience.

Other: ATC tasks and required procedures not specifically or exclusively captured under any of the above variable categories including the use of J-rings, history trails, and strip bay management.

2.2.2 Air Traffic Effectiveness

Safety measures include counts of conflicts or separation violations that occur, ratings of ATCSs and observers of system safety (using notes, questionnaires, or debriefing after each run or series of runs), and various measures and indices of aircraft proximity such as slant range distance and the aircraft proximity index (Paul, 1990).

Capacity is the maximum number of aircraft and aircraft procedures that can be safely handled by the ATCS and the equipment he/she is using. System capacity varies as a function of a number of variables such as weather conditions, radio frequency congestion, and sector size.

Efficiency concerns the frequency and duration of delays along with fuel and resource management. ATC system efficiency encompasses accuracy of data entry, handoffs, and coordination between sectors.

2.2.3 ATCS Functional Performance

Controller functional performance is a diagnostic of how a controller performs tasks as distinguished from controller productive performance. The distinction between this category and ATCS Performance Measures is that, here, the focus is on the process rather than the results or product. The development of the ATCS Functional Performance Model (Figure 2) resulted in the identification of three behavior categories that can effectively classify all ATCS cognitive performance: situation assessment, planning/decision making, and plan/decision implementation.

In the ATC environment, situation assessment entails developing and maintaining the picture. For the purposes of the database, situation assessment represents the following tasks as shown in Figure 5: a) acquiring elements of current situation, b) integrating relevant elements of the situation into the picture, and c) evaluating the situation to identify critical events/problems that need to be addressed. An ATC event can be thought of as any situation that needs attention, regardless of whether it is actually a problem. For example, a conflict might indicate a problem or it might be a routine sequencing and spacing of aircraft onto the final approach. Situational assessment is considered a precursor to other ATCS behaviors. Before any action can be taken, the controller must evaluate the situation to determine if there is a need for action. To be effective, the controller must have knowledge of the status and dynamics of the individual aircraft, knowledge of relevant procedures, and a comprehension of the total situation.

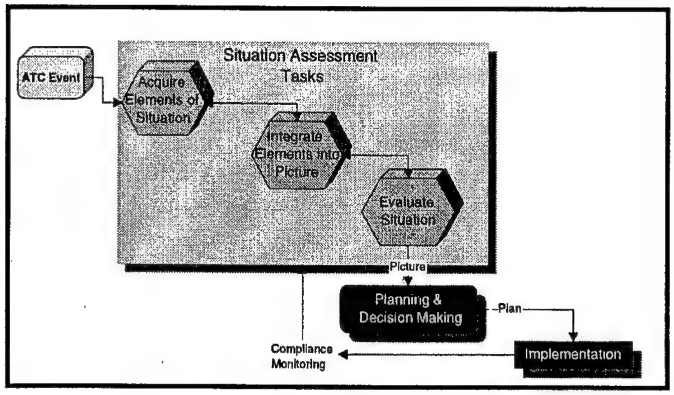

Figure 5. ATCS tasks in situation assessment.

The recognition of ATC events within situation assessment is the impetus for planning and decision-making behavior. Planning and decision making, as shown in Figure 6, is the process of reviewing the situation, determining available options to achieve the desired goal, and deciding which option to implement. The ATCS decides on priorities, aircraft sequence, speed, altitude, and flight routes within the context of the situation. This behavior results in a decision, plan, solution, or strategy. Usually, the resulting plan or decision requires an action (e.g., issuing a clearance for a flight plan change of heading, altitude, or airspeed). Implementation is the ATCS's next step.

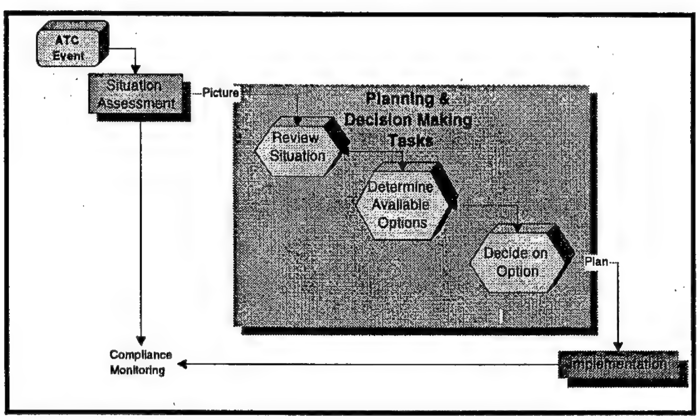

Figure 6. Planning and decision making tasks.

Implementation is the process by which the ATCS acts on the previously determined decisions. Implementation behaviors (Figure 7) include communication and coordination, issuing clearances, and assessing the progress of the plan. Progress assessment, or compliance monitoring, simply means directing part of subsequent situation assessment behavior towards a targeted search for information to evaluate the success of the implementation. This is represented in the model by a feedback loop. The execution of a decision affects the situation and, therefore, the situation must be continuously updated and evaluated.

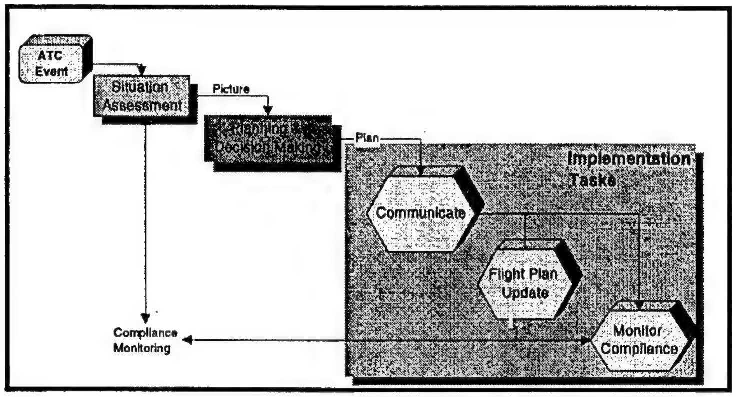

Figure 7. Implementation tasks.

2.2.4 Air Traffic Environments

The NAS includes three types of environments: En Route, TRACON, and Tower (Nolan, 1994). Although it is generally considered part of the en route environment, Oceanic is included in the database as a fourth air traffic environment. The different airspace categories have distinct characteristics.

En Route: En route ATC service provided on Instrument Flight Rules (IFR) flight plans when aircraft are operating between departure and destination terminal areas.

TRACON: A terminal ATC facility associated with an ATC tower that uses radar to provide approach control services to aircraft.

Tower: A terminal facility that uses air/ground communications, visual signaling, and other devices to provide ATC services to aircraft operating in the vicinity of an airport or on the movement area. The tower authorizes aircraft to land or takeoff at the airport controlled by the tower or to transit the Class D airspace area regardless of flight plan or weather conditions (IFR or Visual Flight Rules [VFRs]).

Oceanic: Operating procedures, track structure, and separation standards vary across different air control regions. Minimum separations allowed over the ocean are much larger than in the domestic airspace due to lack of aircraft surveillance and inefficient High Frequency communications. Therefore, oceanic airspace capacity is limited.

3. Conclusion

Reliable information about the performance and effectiveness of ATCSs and how their performance affects the system is essential to understanding system design, selection, training, and operational concepts and procedures. Development and testing of controller performance measures are part of an ongoing process, and the database has been designed to allow easy integration of the most current ATC research findings. Researchers are encouraged to include newly discovered measures of controller performance and to operationally define the existing measures within the database. This will increase the reliability of results and will foster the development of standardized parameters so that valid comparisons between experiments can be made.

Clearly, the ATCS is a vital element of ATC system operations, but there is a gap in understanding the impact of changes in controller performance on system effectiveness. New, valid measures of controller performance are needed to understand factors that improve or degrade performance. A solid understanding of those performance factors is particularly important to evaluate the impact of the various automation concepts in ATC system design that are being proposed.

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Appendix A

Performance Measurement Database

Primary Reference	Additional Resources						NAME	ABBREVIATION	DEFINITION	CONFLICT	COMPLEXITY	ERROR	COMMUNICATION	TASKLOAD	WORKLOAD	OTHER	SYSTEM SAFETY	SYSTEM CAPACITY	EFFICIENCY	SITUATION ASSESSMENT	PLANNING & DECISION MAKING	IMPLEMENTATION	EN ROUTE	TRACON	TOWER	OCEANIC
4	2	5	42	44			Standard conflict en route variable	SCNF (ER)	5 miles lateral and 1,000 foot vertical (> FL290 = 2000ft vertical)	X		X					X			X	X	X	X			X
4	2	5	42	44			Standard conflict duration variable	SCNFD (ER)	5 miles lateral and 1,000 foot vertical (> FL290 = 2000ft vertical)	X		X					X			X	X	X	X			X
4	2	5	42	44			Standard conflict terminal variable	SCNF (TERM)	3 miles lateral and 1,000 foot vertical	X		X					X			X	X	X		X	X	
4	2	5	42	44			Standard conflict cumulative durations variable	SCNFD (TERM)	3 miles lateral and 1,000 foot vertical	X		X					X			X	X	X		X	X	
4	5	31					User specifiable conflict variable	XCNF (ER)	User specifiable conflict criteria for lateral and vertical separation	X		X					X			X		X	X	X		X
4	5	31					User specifiable cumulative durations variable	XCNFD (ER)	User specifiable conflict criteria for lateral and vertical separation	X		X					X			X		X	X	X		X
4	5	31					User specifiable terminal variable	XCNF (TERM)	User specifiable conflict criteria for lateral and vertical separation	X		X					X			X		X		X	X	
5	10	42	62				Primary conflict measure for aircraft that are on final approaches and are in trail of one another	LCNF	Measures longitudinal conflicts of aircraft on approach	X		X					X			X		X		X	X	
5	10	42	31	62			The cumulative durations of longitudinal conflicts	LCNFD	The conflict duration in seconds	X		X					X			X		X		X	X	
62	5	10					Parallel conflict frequency variable	PCNF	Frequency of conflicts between aircraft on simultaneous parallel approaches	X		X					X			X		X		X	X	
62	5	10					Parallel conflict frequency cumulative durations variable	PCNFD	Duration of conflict for aircraft pair conflicting on simultaneous parallel approach	X		X					X			X		X		X	X	
5	42	31					Between sector conflict frequency variable	BSCNF	Conflict between aircraft pair when each aircraft is under control by different controller	X		X	X				X			X		X	X	X	X	X

Primary Reference	Additional Resources						NAME	ABBREVIATION	DEFINITION	CONFLICT	COMPLEXITY	ERROR	COMMUNICATION	TASKLOAD	WORKLOAD	OTHER	SYSTEM SAFETY	SYSTEM CAPACITY	EFFICIENCY	SITUATION ASSESSMENT	PLANNING & DECISION MAKING	IMPLEMENTATION	EN ROUTE	TRACON	TOWER	OCEANIC
5	42	31					Between sector conflict frequency cumulative durations variable	BSCNFD	Duration of conflict between an aircraft pair when each aircraft is under control from a different controller	X		X	X				X			X		X	X			X
44	5	10	42	31	62		Aircraft proximity index variable	API	API is a weighted measure of conflict intensity where 100 is a mid-air collision and 1 is a minor violation of the separation standards	X		X					X				X	X	X	X		X
4	5						Airspace conflict frequency variable	ASCNF	Frequency of intrusion into restricted airspace	X		X					X					X	X	X	X	X
4	5						Airspace conflict frequency cumulative durations variable	ASCNFD	Duration of the intrusion into restricted airspace	X		X					X					X	X	X	X	X
							Complexity measures activity variance	CMAV	Measure of aircraft clustering within a user specifiable criterion such as 10 miles. The higher the index, the more aircraft are clustering and potentially more likely to conflict		X			X			X	X	X		X	X	X	X		X
5	10	19	42				Altitude - Complexity Measures	ALT	Frequency of altitude clearances issued during a run		X		X	X			X	X	X		X	X	X	X		X
5	19	42					Heading - Complexity Measures	HDG	Frequency of heading clearances issued during a run		X		X	X			X	X	X		X	X	X	X		X
5	10	19	42				Speed - Complexity Measures	SPEED	Frequency of speed clearances issued during a run		X		X	X			X	X	X	X	X	X	X	X		X
4	5	10	42				Missed approaches - Non Conflict Errors	MISSAPP	Frequency of missed approaches executed during a run		X	X		X			X	X	X			X		X	X	
5							Handoff misses - Non Conflict Errors	HOFFMISS	Frequency in which the aircraft crossed the sector boundary before being handed off			X	X				X	X	X			X	X	X		X
5							Handoff errors - Non Conflict Errors	HOFFERR	Frequency with which the aircraft was handed off to the wrong controller			X	X				X	X	X			X	X	X		X
4	5						Number of hold/turn delays	NDLY	The frequency of hold messages sent to aircraft and the number of turns of greater than 100 seconds duration – Non Conflict Errors		X	X	X				X	X	X		X	X	X	X		

Primary Reference	Additional Resources						NAME	ABBREVIATION	DEFINITION	CONFLICT	COMPLEXITY	ERROR	COMMUNICATION	TASKLOAD	WORKLOAD	OTHER	SYSTEM SAFETY	SYSTEM CAPACITY	EFFICIENCY	SITUATION ASSESSMENT	PLANNING & DECISION MAKING	IMPLEMENTATION	EN ROUTE	TRACON	TOWER	OCEANIC
5	42						Communication Delay	COMDLY	The accumulated time variable based on the du4rations of time between the aircraft calls for service and the controllers initial response			X	X				X	X	X			X	X	X		
5	42						Number of communication delays	COMDLYNBR	This is the cumulated frequency of COMDLY's that exceed 20 seconds			X	X				X	X	X			X	X	X		
5	42						Voice frequency - Communication Activity	VOIFREQ	The number of push-to-talks accumulated during the run				X					X	X			X	X	X	X	X
5	42						Voice duration - Communication Activity	VOIDUR	The total duration of communications during a run				X					X	X			X	X	X	X	X
5							Controller keystrokes - Communication Activity	CKEY	The number of keystrokes entered at the controller's keyboard				X	X					X			X	X	X		X
5	10	21					Pilot keystrokes - Communication Activity	PKEY	The number of keystrokes entered at the simulation pilot's keyboard				X	X					X			X	X	X	X	X
4	5						Number of flights	NFLT	The number of flights accumulated during an experimental run					X			X	X	X							
4	2	10	42				Landings	LAND	The number of landings that occurred during an experimental run					X				X	X		X	X		X	X	
4	2	42					Departures	DEPART	The number of departures that occurred during an experimental run					X				X	X		X	X		X	X	
4	2	5	42				Handoffs	HANDOFF	The number of hand-offs that occurred during an experimental run					X				X	X		X	X	X	X		X
5	19	21					Air traffic workload input technique	ATWIT	Subjective workload measured at standard intervals during the simulation						X			X	X	X			X	X	X	X
19							Operational errors -Safety	N/A	An operational error is one in which the separation standards were violated			X					X			X	X	X	X	X	X	X
4	19	39	31				Conflict alerts - Safety	N/A	The number of conflict alerts which occurred during the simulation	X		X		X			X			X		X	X	X	X	X

Primary Reference	Additional Resources						NAME	ABBREVIATION	DEFINITION	CONFLICT	COMPLEXITY	ERROR	COMMUNICATION	TASKLOAD	WORKLOAD	OTHER	SYSTEM SAFETY	SYSTEM CAPACITY	EFFICIENCY	SITUATION ASSESSMENT	PLANNING & DECISION MAKING	IMPLEMENTATION	EN ROUTE	TRACON	TOWER	OCEANIC
19							Use of halo (J Ring) - Safety	N/A	The number of times the J-ring or halo was used during an experimental run							X	X			X		X	X			
19	39						Vector lines - Safety	N/A	The number of times the vector lines were used during an experimental run							X	X			X		X	X			
19	39						History trail - Safety	N/A	Number of times history trails were used during an experimental run							X	X			X		X	X			
19	39						Data block offset - Safety	N/A	Number of times the data blocks were offset during an experimental run							X	X			X		X	X			
19	4	21					Average time in sector - Capacity	N/A	Average time an aircraft spent under a controller's control					X				X	X		X		X	X		X
4	19						Fuel consumption - Capacity	FUEL	Fuel used by each aircraft in an experimental run for a standard distance							X			X		X	X	X	X	X	X
19							Taskload per aircraft - Capacity	N/A	Number of tasks or operations performed per aircraft					X				X	X		X	X	X	X	X	X
19							Communication efficiency - Capacity	N/A	Extent to which a controller can handle communication tasks				X	X				X	X			X	X	X	X	X
19							Data entry efficiency - Capacity	N/A	Extent to which a controller can handle data entry tasks					X				X	X			X	X	X	X	X
19							Altitude assignments – Capacity	N/A	Extent to which a controller correctly assigns altitudes to aircraft under his or her control					X			X	X	X	X	X	X	X	X		X
19	31						R-Data entries - Performance	N/A	Extent to which the radar controller enters data quickly and accurately					X				X	X	X	X	X	X	X		X
19							R-Data entry errors - Performance	N/A	Number of data entry errors accumulated by the radar controller			X		X			X		X			X	X	X		
19	31						D-Data entries - Performance	N/A	Extent to which the data controller enters data quickly and accurately					X				X	X			X	X	X		
19							D-Data entry errors - Performance	N/A	Number of data entry errors accumulated by the data side controller			X					X		X			X	X	X		

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19							Timed performance of functions - Performance	N/A	Measures of task times to complete various ATC functions					X					X	X	X	X	X	X	X	X
19							Measures of quality of service - Performance	N/A	ATC services			X		X		X	X	X	X			X	X	X	X	X
19	2	37	44	65			Measures of controller performance as evaluated by expert observers - Performance	N/A	Over-the-shoulder ratings of various performance dimensions by subject matter experts	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
19	65						Strip bay flight strip management - Performance	N/A	Measure of how well the participant is managing flight strips			X		X		X	X	X	X	X		X	X	X	X	X
4	19						Communication counts	N/A	The number of communications				X	X					X			X	X	X	X	X
19							Average workload	N/A	This is an average or an overall rating of workload given at the end of the experimental run				X		X			X	X	X	X	X	X	X	X	X
19	37						Between-sector coordination	N/A	Measure of the taskload generated by coordinating with controllers in adjacent sectors					X	X			X	X	X	X	X	X	X		X
19	37						Within - Sector coordination (R&D teamwork)	N/A	Measure of the taskload generated by the coordination between radar and data controllers					X	X			X	X	X	X	X	X	X	X	X
19	40						Environmental factors – Usability	N/A	Measure of the impact of environmental factors such as workspace lighting and anthropometry on usability					X		X	X	X	X			X	X	X	X	X
19	65	66					Accessibility of controls and flight strips - Usability	N/A	Measure of the usability of the flight strips and accessibility of the flight strips bay					X		X	X	X	X			X	X	X	X	X
19							Traffic characteristics - Simulation Fidelity	N/A	Fidelity of the simulated traffic as representative of the real world		X			X		X		X		X			X	X	X	X
42							Closest-point-of-approach	CPA	Slant range of the aircraft pair in conflict measured in feet	X		X					X							X	X	

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4	42						Number of aircraft path changes	SPTH	Number of times the aircraft changed heading speed or altitude		X			X					X	X	X	X		X	X	
4	21	42					Distance aircraft under control	FLOWN	Distance flown in miles the aircraft handled flew in the simulation		X			X					X					X	X	
42							Number of pilot messages	PMSG	Number of simulation pilot messages issued during an experimental run of the simulation				X	X										X	X	
42							Number of acquisitions	ACQ	Number of times aircraft acquired the localizer during an experimental run		X			X										X	X	
4	21	42					Number of path change/data link messages	PATH	Total number of altitude, heading or speed changes issued by the controller during an experimental run		X			X					X					X	X	
10							Hold messages - Control Directives	HOLD	Number of hold clearances issued during an experimental run		X		X	X									X			
10							Information, clearances, reports, beacon, miscellaneous - Control Directives	MISC	Number of miscellaneous clearances issued during an experimental run		X		X	X		X						X				
4	31						Hand offs to subject - Control Directives	HOIN	Number of hand-offs received by the participant during an experimental run		X		X	X								X				
4	31						Hand off from subject - Control Directives	HOUT	Number of hand-offs the participant made during an experimental run		X		X	X								X				
4							Maximum number of instantaneous aircraft controlled - Occupancy	NIAC	Maximum number of aircraft that were under control during an experimental run		X			X												
4	21						Number of ground-to-air contacts – Communications	NG2A	Total number of communications between controllers and pilots during an experimental run				X	X					X							
4	21						Duration of ground-to-air communications (seconds) – Communications	DG2A	Total duration of communications between controllers and pilots during an experimental run				X	X					X							

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							Deliberate pilot noncompliance or miscompliance – Simulation Conditions		Scenario variable where simulation pilots may not follow clearances accurately or may make path changes without a clearance		X	X	X	X				X								
44							Simulation of equipment errors and/or failures – Simulation Conditions		Scenario variable where equipment failures test the controller's ability to work under degraded modes of operation		X			X		X							X	X	X	X
44							The use of unusually high traffic rates to maximize pressure on the controllers – Simulation Conditions		Scenario variable where unusually high traffic loads present a stress test to the controller		X			X									X	X	X	X
44	10						Slant Range Miss Distance -measure of aircraft separation	SRMD	The shortest distance between two aircraft in conflict. It is measured by a straight line formed by the aircraft centers	X		X					X									
44	10						Vertical distance between A/C (in feet)	DV	Vertical component of slant range. It is measured in feet	X							X									
44	10						Horizontal distance (NMI)	DH	Horizontal component of slant range. It is measured in nautical miles	X							X									
42	10						Blunders and associated conflicts	BLNDCNF	An unexpected turn by an aircraft already established on the localizer toward another aircraft on an adjacent approach	X		X		X			X							X		
42	10						Blundering aircraft and the next aircraft receiving a path change message	BLUNDERS	Planned deviations from the localizer in which one aircraft crosses into the landing path of another	X		X		X			X							X		
42	10	61					Snapshot of aircraft within a user-specified distance or time frame surrounding a particular event.	SNAPSHOT	Offers ability to go back into the data and extract events surrounding a specific incident (such as an intentional blunder)	X		X	X			X	X							X		
16	10						Entry into NTZ	NTZNTRY	Time an aircraft entered the no transgression zone	X		X		X			X							X		
16	10						Exit from NTZ	NTZEXIT	Time an aircraft that was in the no transgression zone left the zone	X		X		X			X							X		

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10	16	Range and altitude separation of conflict, or aircraft tracking code for pilot, or NTZ actions	TRACK/SEP	Range and altitude separation of conflict, or aircraft tracking code for pilot, or NTZ actions	X		X					X							X		
10		Completed pilot keyboard messages	PILOTMSG	Completed pilot keyboard messages				X	X												
4	10	Pilot keyboard entry errors (these are not necessarily pilot errors. A controller may have given an incorrect command).	PILOTERR	Every backspace is counted, and if a CLR key is struck, every key in that message is counted as an error			X	X	X					X							
10	16	Deviation (feet, L-left, R-right), MX (maximum deviation in feet)	DEVIATION	Deviation from the ILS enter line in feet			X				X	X							X	X	
10		Horizontal separation (miles) - Conflicts	HSEP	Horizontal separation of aircraft pair in conflict and is measured in miles	X		X					X							X		
10		Vertical separation (feet) - Conflicts	VSEP	Vertical separation of an aircraft pair in conflict measured in feet	X		X					X							X		
10	39	Relationship of ILSs (B-1 side-by-side, B-2 an ILS between, B-3 two ILSs between) - Conflicts	RELATION	Relationship of ILSs (B-1 side-by-side, B-2 an ILS between, B-3 two ILSs between)	X		X					X							X		
10		Clearance - Instantaneous Aircraft Count	CLEARED	Number of clearances issued during an experimental session		X		X	X								X				
10		Report messages - Instantaneous Aircraft Count	REPORT	Number of report messages that occurred during an experimental run				X	X								X				
10		Frequency transfers - Instantaneous Aircraft Count	FREQXFER	Number of frequency transfers that occurred during an experimental run				X	X								X				

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10							Cancel flight - Instantaneous Aircraft Count	CANCEL	Number of cancelled flights that occurred during an experimental run				X	X				X	X							
12							Percent of time controller spends looking at a particular display	None	The premise for this measure is that the more difficult a task, the more time a controller will spend looking at the display		X			X	X			X	X				X	X	X	X
12							Amount of in-track time spent inside the final approach fix	None	The amount of controller monitoring inside the final approach fix. This is considered critical because of the separation compression that normally occurs within the vicinity of the outer marker		X			X	X			X	X	X				X		
12							Number of uninterrupted dwell points alternating between two ATC display objects	None	The objective of this measure is to sequentially examine the relative positions of aircraft to other aircraft and aircraft to geographical points on the display		X			X	X			X	X	X			X	X		
14	15	37					Situational Awareness Global Assessment Technique	SAGAT	SAGAT can be used to focus on any one of the tasks within situation assessment. The tasks include acquiring the elements of a current situation, integrating the relevant elements of a situation into a picture, and evaluating the situation		X							X	X	X			X	X	X	X
56	15	26	37				Situation Awareness Rating Technique	SART	The technique is based on the assumption that situation awareness is comprised of three aspects of the operator's task which are the operator's supply attentional resources, demands on those resources and an operator's understanding of the situation		X							X	X	X			X	X	X	X
36							Action Transition Graphs	None	The method involves documenting all actions taken by the operator throughout the session. The graphs show an operator's transition from closed to open loop performance. These graphs are useful for revealing changes in performance in complex systems		X			X					X		X	X	X	X	X	X

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58	37						Behaviorally Anchored Expert Observations	None	These involve ratings of various performance dimensions by expert observers. Rating performance of specific observable controller actions reduces need for observers to make unreliable inferences about controller performance	X	X	X	X				X	X	X		X	X	X	X	X	X
3							Controller Decision Evaluation	CODE	The method presents a traffic situation unfolding in a film/video and requires the controller to determine the next appropriate action	X	X						X			X	X	X	X	X		
55							Verbal Protocol Analysis	None	The goal of verbal protocol analysis is to map how incidents unfold during the completion of a scenario. Types include think-aloud protocols, retrospective verbal reports and cued retrospective verbal reports	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X
69							Behavioral Protocol Analysis	None	The goal of behavioral protocol analysis is to understand the evolution of a scenario in parallel with the controller's behaviors and intentions	X	X	X					X	X	X		X		X	X	X	X
18	26						Critical Incident Technique	CIT	The CIT involves a set of procedures that can be used to collect direct observations of controller behavior to learn about the controller's planning, decision making and problem solving behavior			X					X		X	X	X		X	X	X	X
50	21						Clustering	None	Clustering refers to the degree to which a participant performs actions that are typically performed consecutively, in a consecutive manner. Organized, systematic behavior is expected to be characteristic of well thought out behavior		X			X							X	X	X	X	X	X
4	3						System Effectiveness Measures	SEM	The SEM set measures many different factors associated with the safety and efficiency of the system: confliction, occupancy, communication, and delay	X	X	X	X				X	X	X			X	X	X		

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12							Aircraft Pair Inter-Arrival Error	IAE	The difference between arrival errors of sequential arrival aircraft defined in terms of aircraft actual time of arrival and scheduled time of arrival		X	X							X		X	X		X	X	
33							Subjective Performance Prediction	None	Subjective judgments by subject matter experts can be used in the evaluation process to predict operator performance. Judgments may be made about system design alternatives, procedural alternatives etc.		X	X	X	X			X	X	X	X	X	X	X	X	X	X
20							Task Load	None	Task load is the time required to perform a task divided by the time available to perform the task. Values above 1 indicated excessive task load			X		X					X				X	X	X	X
6							Charlton's Measures of Human Performance in Space Control Systems	None	Charlton's measures to predict human performance in space control systems are divided into 3 phases (pre-pass, contact execution and contact termination) and 3 crew positions (ground controller, mission controller and planner analyst)			X	X				X		X				X	X	X	X
38							Nieva, Fleishman, and Rieck's Team Dimensions	None	Nieva, Fleishman, and Rieck defined five measures of team performance: (1) matching number resources to task requirements, (2) response coordination (3) activity pacing (4) priority assignment among tasks, and (5) load balancing			X	X			X	X	X	X			X	X	X	X	X
46							Unified Tri-services Cognitive Performance Assessment Battery	None	Made up of 25 tests which were selected based on the following criteria (1) used in at least one Department of Defense laboratory, (2) proven validity, (3) relevance and (4) sensitivity to hostile environments and sustained operations			X		X				X	X		X		X	X	X	X
8							Load Stress	None	Load stress is the stress produced by increasing the number of signal sources that must be attended to during a task			X			X								X	X	X	X

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51	7	26	65				Secondary Tasks	None	One of the techniques most widely used to measure workload is the secondary task. The decrement in performance of the secondary task is operationally defined as a measure of workload			X			X								X	X	X	X
54							Analytical Hierarchy Process	AHP	The analytical hierarchy process uses the method of paired comparisons to measure workload. Specifically, subjects rate which of a pair of conditions has the higher workload. All combinations of conditions must be compared						X								X	X	X	X
52	7						Bedford Workload Scale	None	Roscoe described a modification of the Cooper-Harper scale created by trial and error with the help of test pilots at the Royal Aircraft Establishment at Bedford England. The Bedford scale retains the binary decision tree of the Cooper Harper Scale						X								X	X	X	X
63							Computerized Rapid Analysis of Workload	CRAWL	CRAWL is a computer program that helps designers predict workload in systems being designed. CRAWL inputs are mission timelines and task descriptions. Tasks are described in terms of cognitive, psychomotor, auditory and visual demands					X	X								X	X	X	X
11	26						Cooper-Harper Rating Scale	None	The Cooper-Harper Rating Scale is a decision tree that uses the adequacy of the task, aircraft characteristics and demands on the pilot to rate the handling qualities of an aircraft						X								X	X	X	X
45							Crew Status Survey	None	Contains 20 statements describing fatigue status					X	X	X	X						X	X	X	X
59							Dynamic Workload Scale	None	The dynamic workload scale is a seven-point scale developed as a tool for aircraft certification. It has been used extensively by Airbus Industries						X								X	X	X	X

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25							Equal Appearing Intervals	None	Participants rate the workload in one of several categories using the assumption that each category is equi-distant from adjacent categories						X								X	X	X	X
60							Flight Workload Questionnaire	None	The flight workload questionnaire is a four item behaviorally anchored rating scale. The items of the rating scale are workload category, fraction of time busy, how hard had to think, and how felt (relaxed to very stressful)						X								X	X	X	X
23							Hart and Hauser Rating Scale	None	Hart and Hauser used a six-item rating to measure workload during a 9-hour flight. The items were stress, mental/sensory effort, fatigue, time pressure, overall workload and performance						X								X	X	X	X
3							Magnitude Estimation	None	Participants are required to estimate workload numerically in relation to a standard						X								X	X	X	X
32							McDonnell Rating Scale	None	The McDonnell rating scale is a ten point scale requiring a pilot to rate workload based on the attentional demands of a task						X								X	X	X	X
13							Mission Operability Assessment Technique	None	The mission operability assessment technique includes two four point rating scales, one for workload and the other for technical effectiveness. Participants rate both workload and technical effectiveness for each subsystem identified in a task analysis					X	X				X			X	X	X	X	X
68	7						Modified Cooper-Harper Rating Scale	None	A modified Cooper-Harper scale was developed to increase the range of applicability to situations commonly found in modem systems.						X			X					X	X	X	X
22							NASA Bipolar Rating Scale	None	The NASA bipolar rating scale has ten subscales. If a scale is not relevant to a task, it is given a weight of zero. A weighting procedure is used to enhance intrasubject reliability						X								X	X	X	X

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24	7						NASA Task Load Index	NASA TLX	The NASA Task Load Index is a multi-dimensional subjective workload rating technique. In TLX, workload is defined as the cost incurred by human operators to achieve a specific level of performance						X								X	X	X	X
60							Pilot Objective/Subjective Workload Assessment Technique	POSWAT	POSWAT is a ten point subjective scale developed at the FAA Technical Center. The scale is a modified Cooper-Harper scale, but does not include the binary decision tree						X								X	X	X	X
17							Pilot Subjective Evaluation	PSE	The PSE was developed by Boeing for use in certification of the Boeing 767. The scale is accompanied by a questionnaire. Both the scale and the questionnaire are completed with reference to an existing aircraft.						X								X	X	X	X
57							Profile of Mood States	POMS	The shortened version of the Profile of Mood States scale provides measures of self-rated tension, depression, anger, vigor, fatigue and confusion						X	X							X	X	X	X
64							Relative Comparison Technique	None	The basis for using the relative comparison technique is to draw upon the aircrew's expertise with a similar system. Relative data are collected by comparing each possible item to the others.						X								X	X	X	X
49	7						The Subjective Workload Assessment Technique	SWAT	SWAT combines ratings of three different scales to produce an interval scale of mental workload. These scales are time load, mental effort load, and psychological stress load						X								X	X	X	X
41							Workload/Compensation/Interference/Technical Effectiveness	WCI/TE	The WCI/TE rating scale requires participants to rank the sixteen matrix cells and then rate specific tasks. The ratings are converted by conjoint scaling techniques to values of 0 to 100.		X	X		X	X					X	X	X	X	X	X	X

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67							Unstructured Group Discussion	None	Unstructured group discussion is the use of questions that the participants received in advance of the discussions. This technique suited the purpose of exploring the concept of the controller's picture or situational awareness		X								X	X	X		X	X	X	X
55							Shell for Performing Verbal Protocol Analysis	SHAPA	An automated tool that has been developed and used successfully to aid in the analysis of concurrent verbal protocols	X	X		X					X		X	X		X	X	X	X
53							Enhanced Video Recordings	None	A paper by Roske-Hofstrand reported on the use of combined video and eye movement recordings		X									X	X		X	X	X	X
48							Structured Interviews	None	Participants in three groups were asked questions about their action priorities under normal and heavy workloads. Actions rated included scanning the plan view display, sequencing traffic, calling and coordinating, and determining crosspoints		X	X						X	X	X	X		X	X	X	X
27							Critical Incidents Interviews	None	The technique consists of a preliminary interview session to identify unusual or difficult situations encountered by participants followed by a second interview session to review incident descriptions to elicit possible alternatives to each action		X	X								X	X		X	X	X	X
28							Measure of spatial aspects of the controller's mental model	None	Controllers are shown static air traffic scenarios involving aircraft pairs. The controllers are asked to draw on paper the predicted relationship of the aircraft at the point of least separation	X	X									X	X		X	X	X	X
29							Multidimensional scaling	MDS	Multidimensional scaling was used for direct and indirect reconstruction of cognitive maps as well as a diagnostic version of the methodology for studying mental rotation of three-dimensional objects											X	X		X	X	X	X

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1	26						Recall tasks	None	Recall tasks have been used by several researchers to study memory in ATC		X									X			X	X	X	X
43							Dual Coding tasks	None	These are research tasks that require participants to compare perceived and imagined objects, to compare symbols, to make mental transformations, and to perform computations based on representational structures		X									X	X	X	X	X	X	X
30	26	65					Retrospective verbalization	None	This is where participants reflect and verbalize what is going on in an ATC situation that has been pre-recorded. This is used to identify cognitive structures and decision-making strategies.											X	X		X	X	X	X
35	31						Sector size	None	This is the square mileage a sector takes up. The smaller the sector the greater the complexity and task load		X			X				X					X	X		
35							Aircraft mixture	None	This is the mixture of slow and fast moving aircraft. The greater the variety of slow and fast aircraft the greater the complexity due to the potential for overtaking conflicts	X	X			X									X			
35	31						Number of intersecting flight paths	None	This is the number of jet routes or victor airways that cross within the sector. The greater the occurrence the more stringent the requirement for spacing and sequencing as well as vertical separation to avoid conflicts at these crossing points.	X	X			X			X	X	X	X			X	X		
35	37						Number of required procedures	None	This is the number of procedures used to move an aircraft through the sector airspace.		X		X	X				X	X	X	X	X	X	X	X	X
35							Number of military flights	None	Military flights may require special handling that imposes additional taskload. They often make special requests, do not always conform to procedures, and fly in formations and may break formation during a flight imposing additional task load on the controller		X			X				X		X	X	X	X			

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35	34						Amount of coordination	None	Coordination requires communication with ground controllers and imposes additional task load due to point outs and waiting for the coordinating sector to approve or disapprove		X		X	X					X				X	X		
35	34						Airline Hubbing	None	Airline hubbing cause more complexity by bringing in many aircraft with the same company and similar call signs and the fact that many aircraft are arriving and departing on few airways		X			X					X				X	X		
35							Weather	None	Weather produces complexity by limiting the airspace available for maneuvering, blocking airways, and limiting altitudes available for vertical spacing		X			X			X	X	X				X	X	X	X
35							Complex aircraft routings	None	Complex aircraft routings require more attention to aircraft due to crossing points, turns and potential conflicts with other aircraft. Ideally controllers would like to send an aircraft direct to a fix outside the sector		X			X			X	X	X				X			X
35	34						Restricted areas, warning areas and military operating areas	None	Restricted areas restrict the amount of airspace available for spacing and sequencing aircraft. They have the same effect as reducing sector size		X			X				X					X			
35	34						Requirements for longitudinal spacing and sequencing	None	Increase spacing requirements limit the amount of aircraft one can have in the sector due to fixed sector size	X	X							X					X			X
35	34						Adequacy of radar and radio coverage	None	Incomplete radar or radar coverage causes additional complexity due to the lack of automated aids available with the radar and the need to relay information from aircraft that are in radio coverage to aircraft that are not directly accessible		X			X			X	X	X				X			X
35	34						Radio frequency congestion	None	This adds to complexity due to the increased difficulty in communicating with a large number of aircraft on the same radio frequency		X		X	X			X	X	X				X	X	X	X

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Appendix B

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